Spatial Network Analysis for Multimodal Urban Transport System

A Term Paper

Submitted to the

Professor Dr. Baqer Al-Ramadan

In partial fulfillment of the requirement of an elective course

Introduction to Geographic Information System (CRP 514)

By

Asadullah Khan, id: 200901270, Construction and Engineering Management, KFUPM, KSA.

Jan. 1, 2012

Synopsis

This term paper intends to fulfill for the 'CRP514-Introduction to GIS' course requirements for my ME program in Construction Engineering and Management. This paper reviews the Spatial Network Analysis for Multimodal Urban Transport Systems (SNAMUTS) and its application in Perth (Australia) and Copenhagen (Denmark) to assess comparative performance their transport systems. SNAMUTS is a GIS-based tool designed for urban transport system modeling. Performance measurement in terms of catchment and centrality is the emphases in this paper.

TABLE OF CONTENTS

List of Figures:

List of Tables:

List of Maps:

1. Background

1.1. Introduction

1.1.1. Overview

"*Geographic Information allows us to apply general principles to the specific conditions of each location, allows us to track what is happening at any place and helps us to understand how one place differs from the other. Geographic information is thus, essential for effective planning and decision making in modern society*" [Bermhardsen, 3rd. edition, chapter-1]

1.1.2. Perth and Copenhagen

Perth-capital city of Australia for its fast urban growth is very soon to overtake Copenhagen-Denmark's capital. Perth is compared with Copenhagen for many commonalities between the two cities. Both Pert and Copenhagen are capitals of their countries. In 2008-2009, 1.68 million citizens have been reported in Perth and there are 1.84 million inhabitants in Copenhagen at that time. However, Perth has low density population spreading over 7,270 sq. km metropolis area as compared to Copenhagen's 2780 sq. km. area. The urban density of 13.6 residents and 6.3 jobs per urbanized hectare in Perth is almost half than that in Copenhagen consisting of 25.2 residents and 13.5 jobs per hectare. [Scheurer, 2010]

Both cities demonstrated fast spatial expansion after WWII. Both cities had pre-WWII urban transport system consisting of trams, trains, metros complemented with urban busses in downtowns. Completely or partially, urban transport systems in both cities were abandoned for commercial constraints and some routes for non-popularity. Both cities reinstated and modernized it later with improved efficiency and effectiveness.

For many more other technical commonalities of transport system and spatial comparativeness between Perth and Copenhagen, both cities are considered as competitors in this respect and comparison of their urban transport system is convincing.

1.1.3. SNAMUTS

SNAMUTS is a GIS-based tool for transport planning models which focuses on accessibility and land-transport use context. SNAMUTS was adapted from an urban design based tool measuring the performance of footpaths and streets in Australian and overseas cities. SNAMUTS was designed by GAMUT associates of Australia to measure performance of public transport networks in their land use context for streets and pedestrians at very small scale.

Later its capacity was enhanced to assess accessibility and service availability in term of catchment and centrality of urban public transport networks. The SNAMUTS was further refined to undertake a comprehensive before-and–after comparison of Perth network performance after improvements and with that of Copenhagen.

1.2. Acronyms

1.2.1. Activity Nodes: These are service points like Rail stations or bus stops.

1.2.2. Centrality- A journey with lowest cumulative impediment value (a measure that uses average travel time along a route segment divided by the frequency of the service) between every pair of nodes on the network.[Scheurer, 2010]

1.2.3. Impediment- What is the ease of movement between adjacent network nodes expressed by time and frequency?[Curtis, 2009]

1.2.4. GAMUT (Governance and Management of Urban Transport) - is a collaborative research centre dedicated to promoting and supporting sustainable urban transport in Australia and the Asia Pacific region. Based at the University of Melbourne, GAMUT works with a network of

researchers to focus attention on the need for innovative institutional design for integrated transport systems.

2. Issues at hand

2.1.1. This paper aims to review performance measuring application of SNAMUTS-GIS-based transport planning model.

2.1.2. Comparison of performance parameters like accessibility and how frequently service is available at any service node to connect all other service nodes will be discussed in this paper in term of Contour Catchment and Centrality. This part of study was completed by applying GIS tool-SNAMUTS on multimodal urban transport network. GIS based maps of urban demography and urban transport networks in both cities are basic inputs to draw conclusion on the issue.

3. Objectives

Unawareness to GIS in general, as usually faced by emerging technologies, is a leading obstacle for utilizing it. This further leads to lack of knowledge of the subject when the turn comes for lacking applications' benefits to Governments, public and private sectors. Poor knowledge and lack of friendly environment in

Asian countries' municipalities does not warrant various sectors of government and public life to adopt GIS.

3.1. Report Objectives

The objectives are derived from the gaps noted during literature review and personal observation of mess created by traffic and pedestrians in our cities of developing countries.

The report will be limited to the understanding of how performance is measured/ compared in SNAMUTS application.

A case study of comparison of multimodal urban transport system of Perth and Copenhagen will be discussed where this application is practiced.

3.2. Limitations

- There is no literature found stating or explaining clearly on how various application of GIS tool were exercised except for vague indications of applications.

4. Methodology

Aiming targets of this report, methodology is selected from the knowledge developed during literature review. More than one method will be utilized as explained hereunder:

4.1. Literature Review

Extensive review of published literature is conducted to develop good insight about the issue. This will help developing those details of research which were not addressed earlier. This will help refining report objectives.

4.2. A Case Study

A Case study, where SNAMUTS tool is being used will be reviewed to compare performance of multimodal transport systems of two capital cities of modern world.

5. Literature Review

The purpose of literature review is to develop knowledge of the subject and about the issues already addressed in various researches. It is few, not many, researchers were found worked on the subject or related issues. Majority of research is conducted by Dr. Jan Scheurer (RMIT University, Melbourne, Australia), and Professor Carey Curtis (GAMUT, Curtin University, Perth Australia), sometimes jointly and individually too by both researchers. There are other names as explained hereunder with their contribution to the subject area.

5.1. Previous Research Work

5.1.1. A researcher [Curtis, 2009] analyses statistics of Perth commuters to say that although majority of citizens in metropolis area prefers private cars

but still 40-50% work based traveling is by public transport. He argued that local government is not meeting public needs in this regards, is the reason for citizens to prefer private cars over most of the routes.

There is a need to measure public transport from traveler's perspective as follows:-

- "*Is there a public transport service?*
- *How frequent is it?*
- *How long will it take me to get there (from door to door)?*"

  [Curtis, 2009]

Keeping in view above questions of prime preference by travelers, although there are other considerable questions, he demonstrated the present conditions of urban transport system and concluded that there is much to be done in public transport to be competitive with car users and to provide equity of access.

To reach to above stated conclusion following indicators of SNAMUTS tool were employed.

- ***"Impediment**: what is the ease of movement between adjacent network nodes expressed by time and frequency?*
- ***Degree centrality**: How many transfers separate a node from the rest of the network?*
- ***Closeness centrality**: What is the ease of movement between a node and the rest of the network?*
- ***Efficiency centrality**: By how much does ease of movement across the network improve?*
- ***Catchment size of 30-minute travel time contour**: How many residents and jobs are accessible within half an hour?*
- ***Straightness centrality**: How competitive is public transport travel with road travel?*

- ***Betweenness centrality****: How are travel opportunities geographically distributed across the network?*
- ***Connectivity Index****: How well integrated is a node within the web of travel opportunities?"*

  [Curtis, 2009]

5.1.2. In a paper by [Verma, Kumari and Tiwary, not dated] for highlighting role of remote sensing and GIS applications in urban planning in India, mention that satellite images by Indian launched satellite SPIN-2 has made possible to visualize road networks with 2m/pixel resolution. Such data is helping to demonstrate zones of air and noise pollution around roads which will be basis for strategic planning to mitigate pollution hazards.

5.1.3. In a research article by [Clarke and Gaydos, 1998], a cellular automaton model using GIS to model future growth patterns of urbanization was designed. Model was based mainly on population and transport network growth in Washington-Baltimore region. Population and transport maps of over last 200 years [Fig.1 and Fig.2] were produced using GIS and these maps were used as input in automaton model to predict growth in next century [Fig.3].

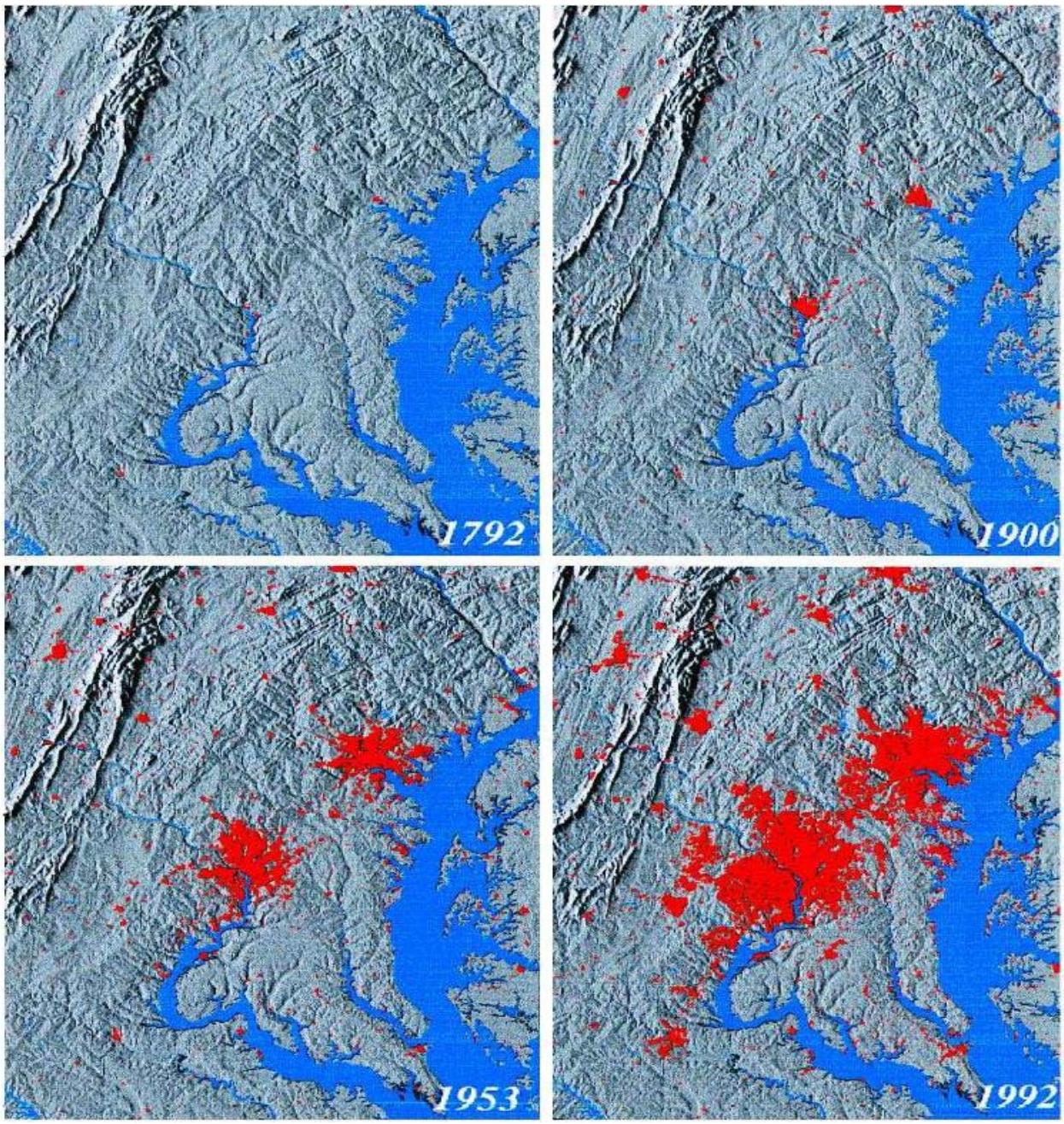


Fig.-1: Historical Urban Development in the Washington/Baltimore Area

[My courtesy to Clarke and Gaydos for copying these pictures from their paper]

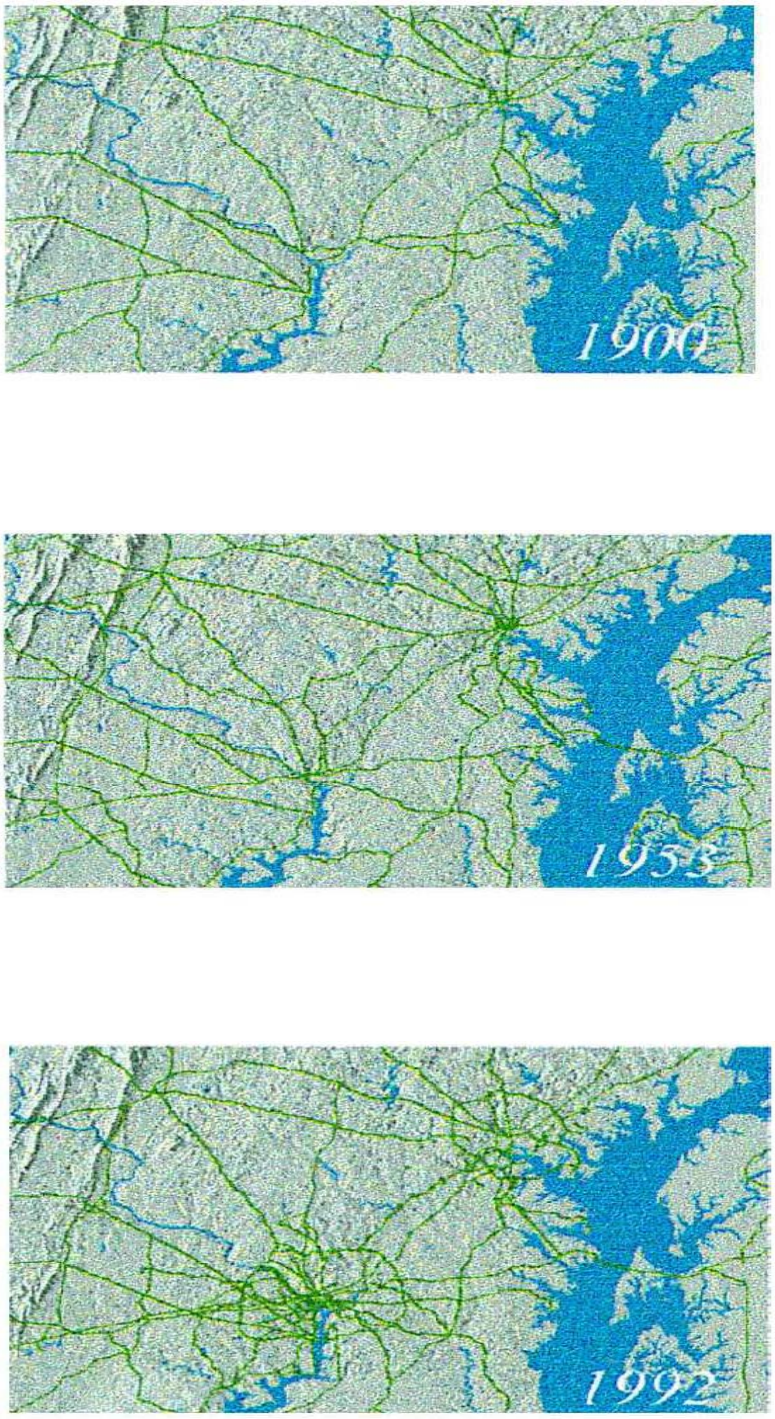


Fig.-2: Historical growth in transportation system in Washington/Baltimore area

[My courtesy to Clarke and Gaydos for copying these pictures from their paper]

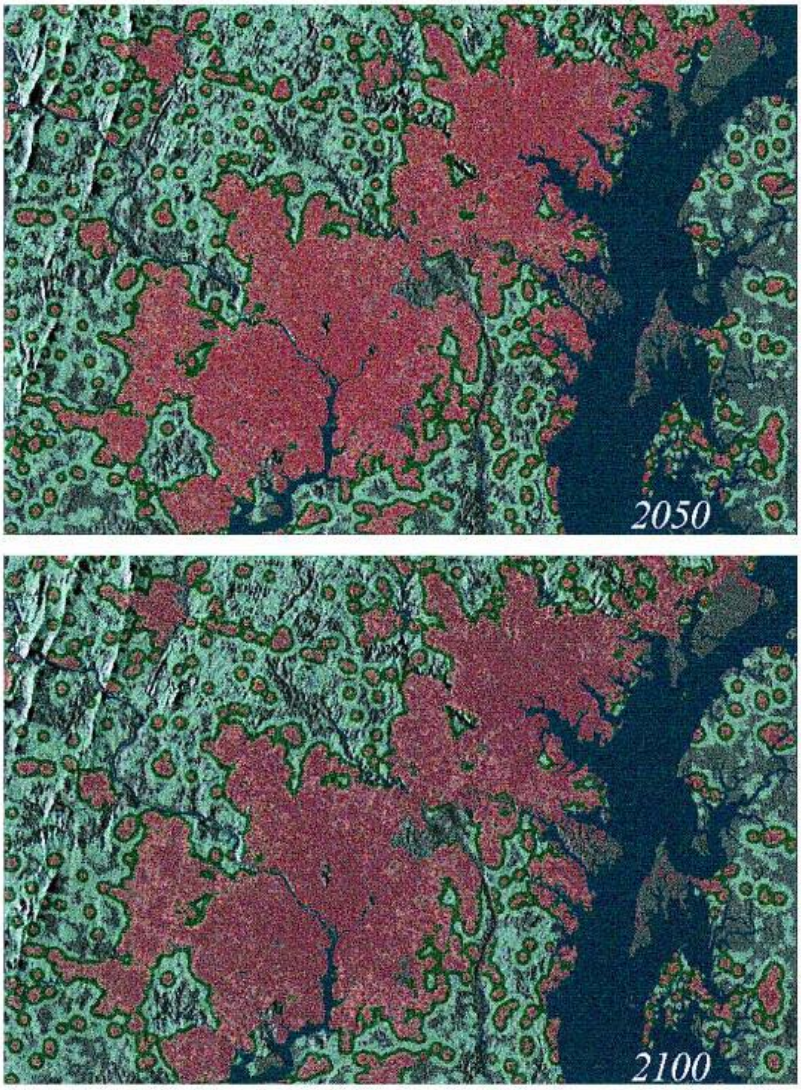


Fig.-3: Washington-Baltimore Urban Growth Predictions

[My courtesy to Clarke and Gaydos for copying these pictures from their paper]

5.1.4. Victoria transport Policy Institute has classified various transport models into categories like Travel Demand Models (TDM), Economic Evaluation models, Integrated Transportation, Land Use Models, Simulation Models, Price elasticities and Induced Growth Models. The institute publishes updates quarterly on development in these models. [Transport Model Improvement, 2011]

5.1.5. Web mapping applications by ESRI and those by Google were studied by undergraduate students [Gioulas, Hannmann and Smith, 2010; soft copy ref. only for large volume] and compared for various map attributes as in table below.

	ESRI Rest	ESRI Web ADF	ESRI Flex API	ESRI JavaScript API	ESRI Silverlight API	Google API	Google Transit
Journey Plan	✓	✓	✓	✓	✓	✓	✓
Multimodal Journey Plan	✓	✓					
Access ArcObjects		✓	✓		✓		
Add/Remove/Reorder map service layers		✓	✓	✓			
Change layer definitions on map service layers	✓	✓				✓	✓
Maptips (point, polygons)	✓	✓	✓	✓	✓		
IDE integration and controls		✓	✓		✓		
Custom Data Sources	✓	✓	✓	✓	✓		
Prints ArcMap (layouts)		✓	✓	✓	✓	✓	✓
Add/Remove/Reorder map service layers		✓	✓		✓		✓
User familiarity	Unknown	Unknown	Unknown	Unknown	Unknown	High	High
Mobile Devices	✓		✓	✓	✓	✓	✓

Table-1: Comparison of Mapping Applications

With the goal to provide on-line journey planner, multimodal transport design with safe sustainable travel options for short trip with Borough of Kingston, London and interactive web site was designed. ArcGIS 9.3.1 was the final choice as sorted out the best among all other options to produce maps and ESRI JavaScript API was found the best to design interactive web application.

5.1.6. In a research article by [Scheurer, 2010] to compare transport network in Perth and Copenhagen, a minimum service standard as benchmark, at first step, was defined like service availability standard is 20-min. frequency during the workdays and 30-minutes frequency during the weekend days, based on public perception for a minimum service standard.

Copenhagen not only satisfies this standard of 20-min. frequency of service but provides its suburban rail system operating at 10-min. frequency at all routes and its buss services like suburban yellow and Express blue; frequency of operating vary between 10 to 20 minutes. Most inner (red) bus service and metro have intervals from 10-min. to as low as 3-min.

Contrary to it, despite railway system is operating at 15-min. interval on most of the routes, thus satisfying SNAMUTS model benchmark, most of buses routes are operating at 30 to 60-min. frequency or even at less frequency during off-business hrs. and weekend days.

For this reason of low frequency buses service in Perth, this portion is not comparable with that of Copenhagen, reason bus service was excluded from GIS-based model-SNAMUTS study. SNAMUTS concludes that Perth needs a total of 25 train sets and 143 buses to be in operation at SNAMUTS min. service standard. Copenhagen requires, satisfying the same

standard, 81 suburban trains, 16 metro trains, 329 buses and 2 ferries. Thus Perth needs to double its transport service to at par with Copenhagen [Scheurer, 2010]

6. Discussion on Case Study

A small scale design tool was developed by GAMUT-Governance and Management of Urban Transport; a research institute in University of Melbourne working in collaboration with outside researchers, to measure preferences by pedestrian and private car movements in certain areas of Perth. The recommendations as the result of this tool are provided to planning department of Western Australian government and metropolis of Perth for development and planning purpose.

Later the same tool's capacity was enhanced by GAMUT to assess commuter's preferences of various routes and services provided by Perth Multimodal Urban Transport System. The multimodal urban transport system in Perth consists of trains, busses, Trams and Metro services connecting suburbs to downtown activity areas.

Further refinement was made in this tool to undertake before-and-after comparison and comparison across different networks as in this case. In this case, comparison of Urban Transport Networks in Perth and Copenhagen were

compared for which one is better than the other and mainly to identify the areas for further improvement in Urban Transport System of Perth.

As the light was shed, in para-1.1.2 of this report, on why Perth is always in competition with Copenhagen, both cities were compared on various parameters. These parameters were both non-GIS based indicators and GIS based indicators.

For non-GIS based indicators statistical data is populated in table-2 below:-

Indicators	Perth (2009)	Copenhagen (2009)	Perth (25-year plan)
No. of activity nodes	71	128	121
No. of services (trains, buses)	169	426	374
Service intensity per 100,000 citizens	11.7	24.4	18.1

Table-2; An overview of non-GIS indicators

For the comparison of various other parameters like Contour Catchment, Degree Centrality, Closeness centrality, and Betweenness centrality, as defined in para-1.2 and para 5.1.5, were measured based on GIS maps of both cities. Both

demographic maps and maps of urban transport systems were collected from GIS department of Perth and from metropolis of Copenhagen for this purpose. Demographic data is populated as in table-3 below:-

Data	Perth (2009)	Copenhagen (2009)
Population	1,445,078	1,748,380
Metropolis Area (sq. km)	7270	2780
Urban Density (residents per hectare)	13.6	25.2
Jobs (employees per hectare)	6.3	13.5

Table-3: Demographic information of Perth and Copenhagen [Scheurer, 2010]

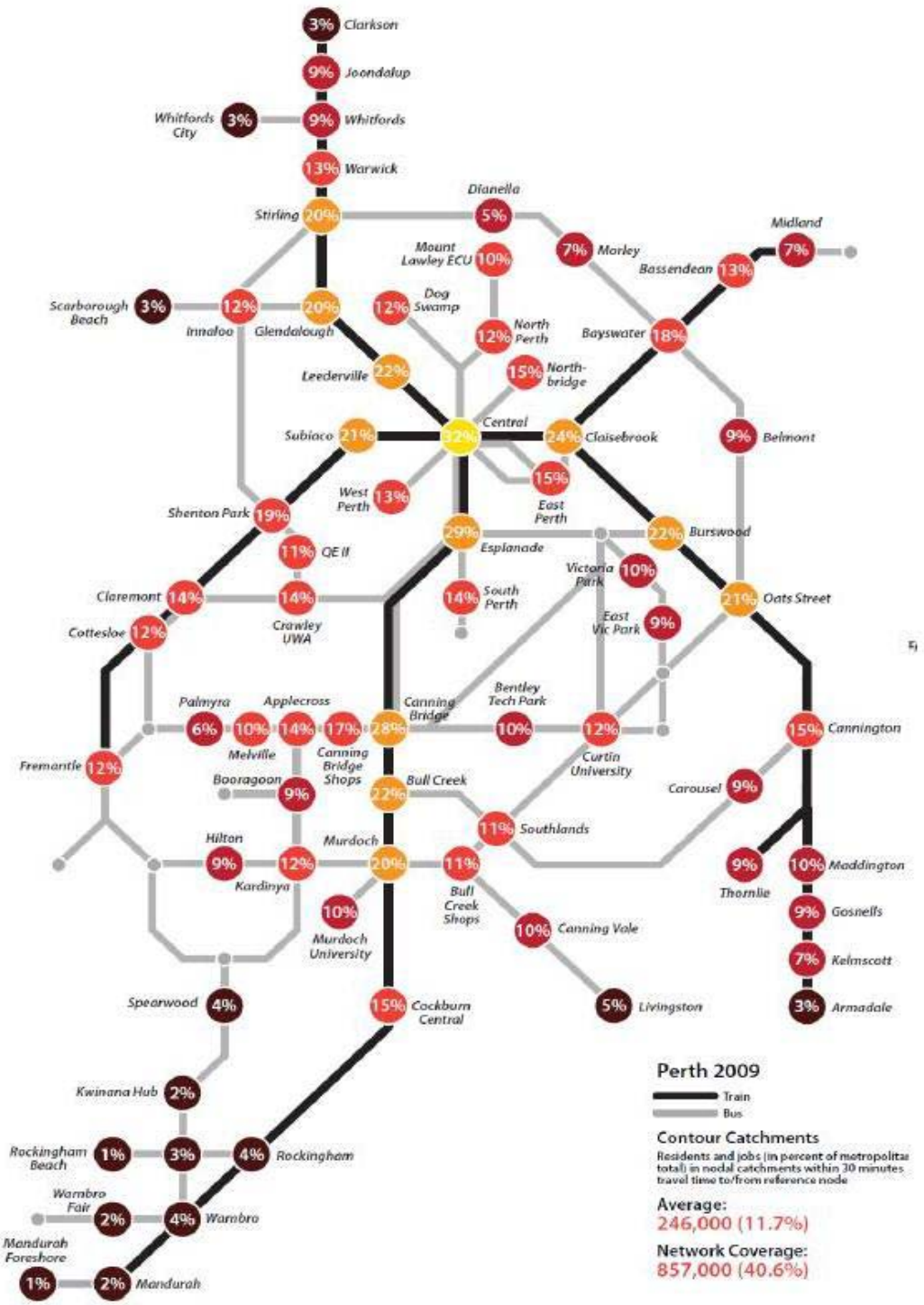
GIS maps as collected from both cities' government, were reproduced in ArcGIS 9.3.1 version. Application of ArcGIS to create buffers of 800-meter circle around train or metro stations and buffer of 400-meter linear corridor from urban bus routes on multimodal urban transport maps was used and a new layer with buffers was created. These distances will enable pedestrians to approach nearest node from work or residence within 30-minute walking distance. The convention of 30-minute walking distance is universally agreed for one-way trip in cities [Scheurer, 2010; para 4.3].

Overlaying application of ArcGIS was the second application of GIS employed to combine feature in two input layers; demographic maps and transport maps to create a new datasets. The resultant attribute tables were translated into indicators as described below for both cities and resultant maps with symbology and labels were also produced for each of following indicators.

30-min. Contour Catchment:

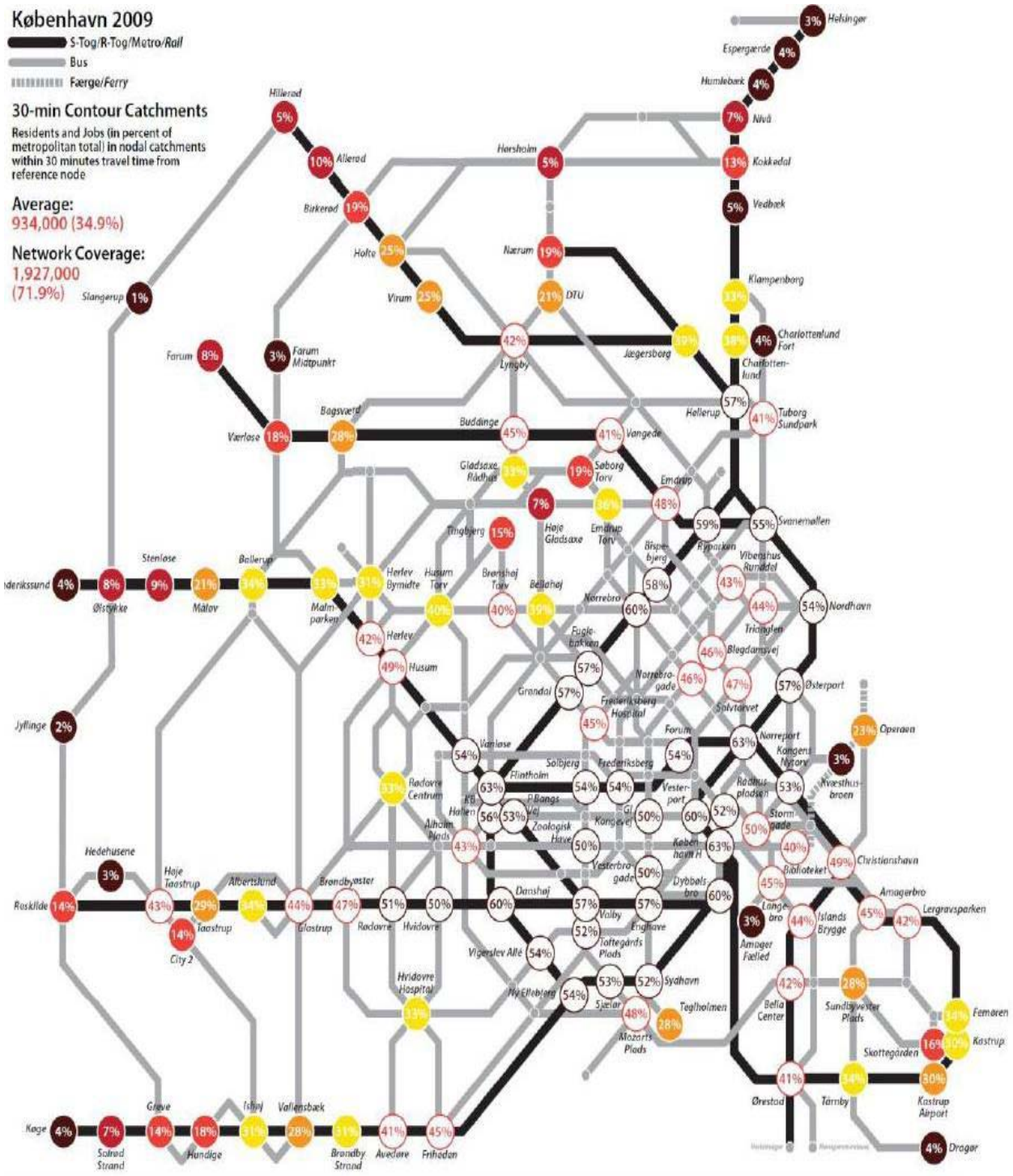
This indicator shows how many residents and jobs can be accessed within 30-min time budget to and from a point of reference. The Map-1 and Map-2 on next pages show contour catchment for each node on Perth and Copenhagen transport networks. The average figure on this indicator is 11.7% for Perth while in Copenhagen it is three times as high as 34.9%. It means that 11.7% inhabitants and jobs in Perth and 34.9% in Copenhagen can access their multimodal transport within 30 minutes from their point of residence or work whereas the networks were designed for maximum coverage of 40.6 % in Perth and 71.9% in Copenhagen regardless of 30-min. approach.

These results with same figures (11.7 and 34.9%) also infer that both population and job density in Copenhagen is also three times higher as compared to that in Perth.[Scheurer, 2010; para 4.3]



Map-1: 30-minute Contour Catchment at Perth metropolis transport network

[Courtesy to Monash Institute of Transport Studies for copying this map]



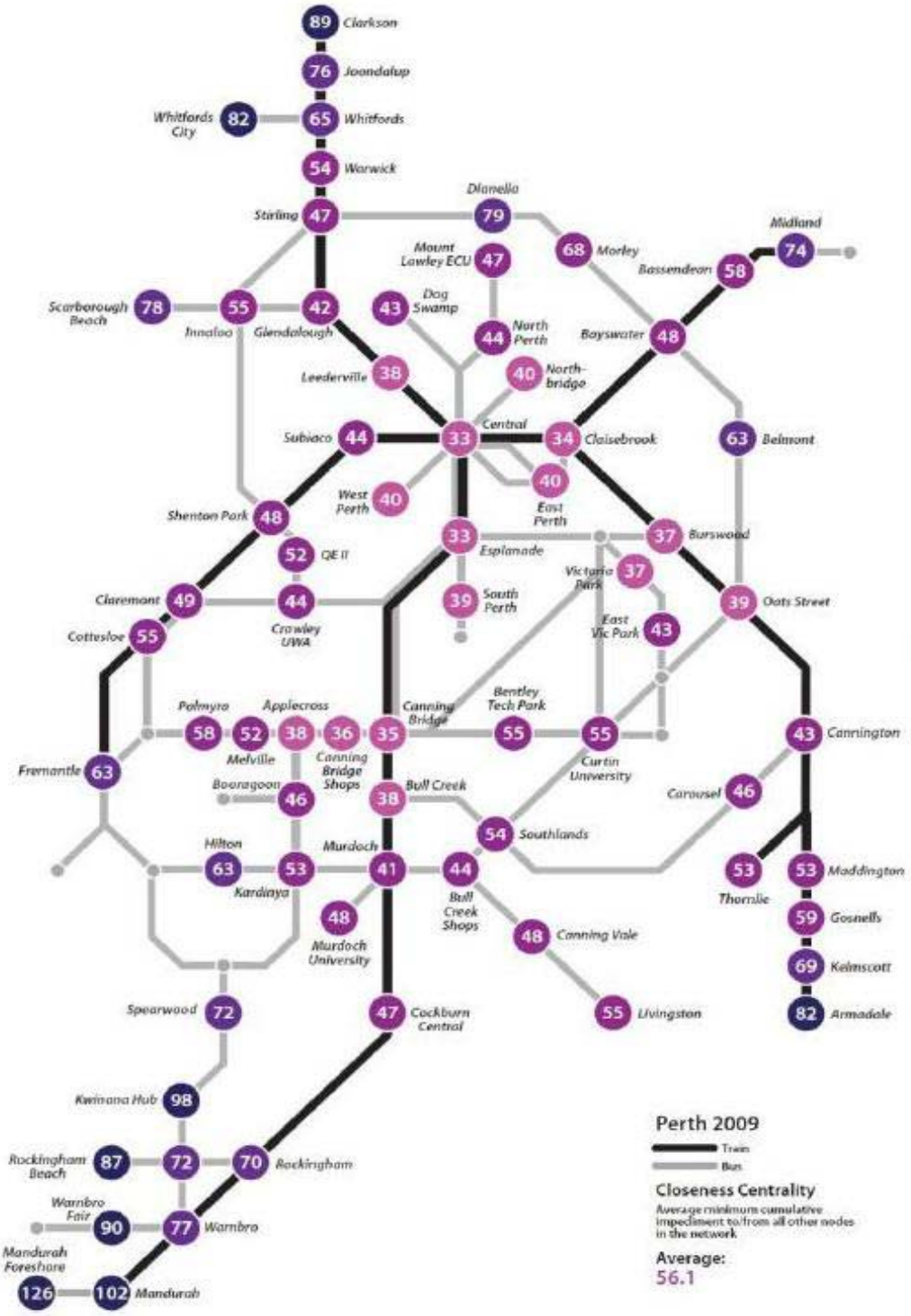
Map-2: 30-minute Contour Catchment at Copenhagen metropolis transport network

[Courtesy to Monash Institute of Transport Studies for copying this map]

Closeness Centrality:

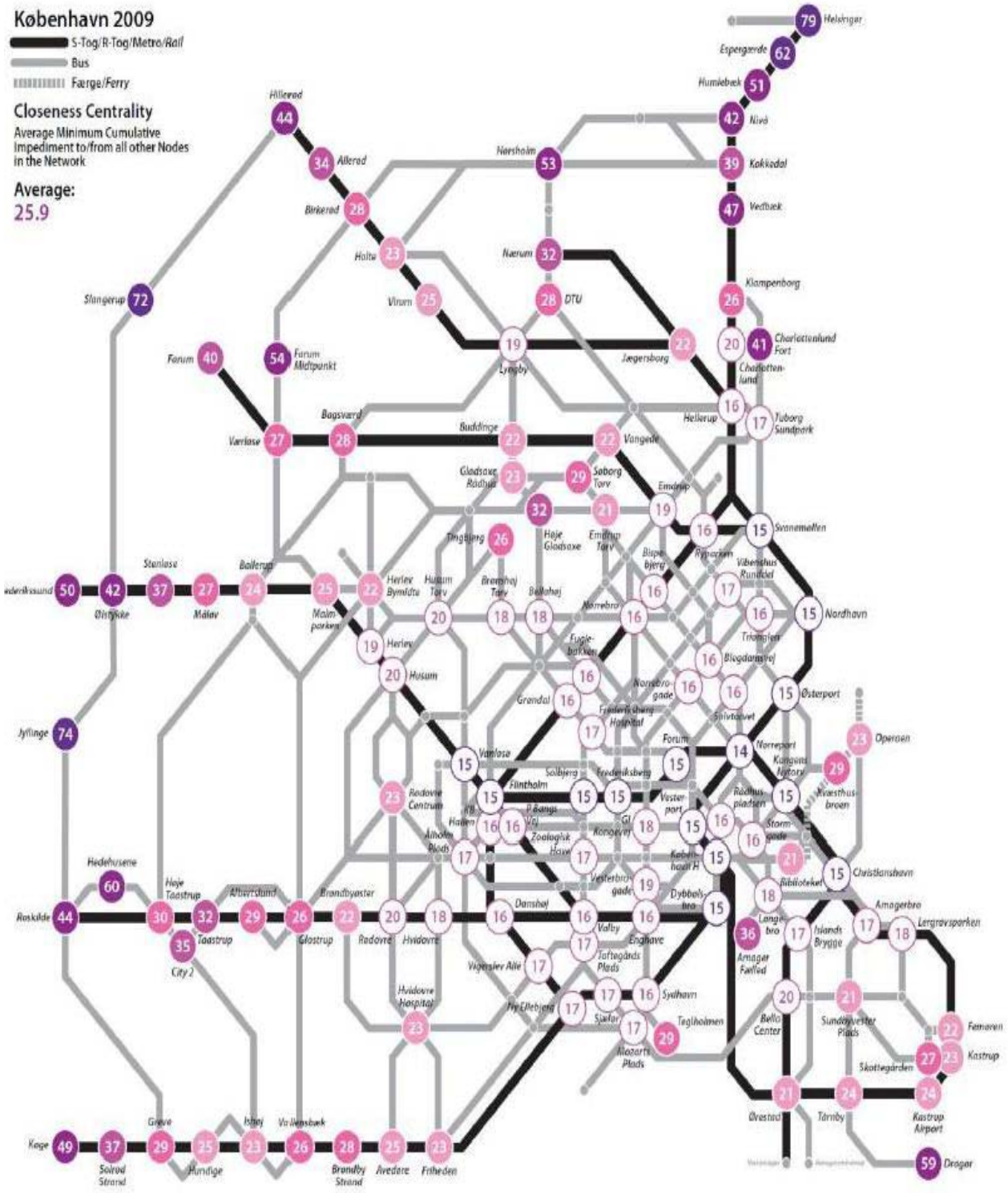
This indicator is defined as ‘A journey with lowest cumulative impediment value between every pair of nodes on the network. Impediment value is explained as average travel time along a route segment divided by the frequency of the service at connecting nodes [Curtin, 2009]. Lower index values as indicated on the Map-3 and Map-4 on next pages show greater centrality.

Average closeness centrality value per activity node in Perth is found 56.1, while in Copenhagen it is 25.9. The reason for this substantial difference in performance between the two cities is primarily related to network density and service provision. [Scheurer, 2010; para 4.1]



Map-3: Closeness Centrality at Perth metropolis transport network

[Courtesy to Monash Institute of Transport Studies for copying this map]



Map-4: Closeness Centrality at Copenhagen metropolis transport network

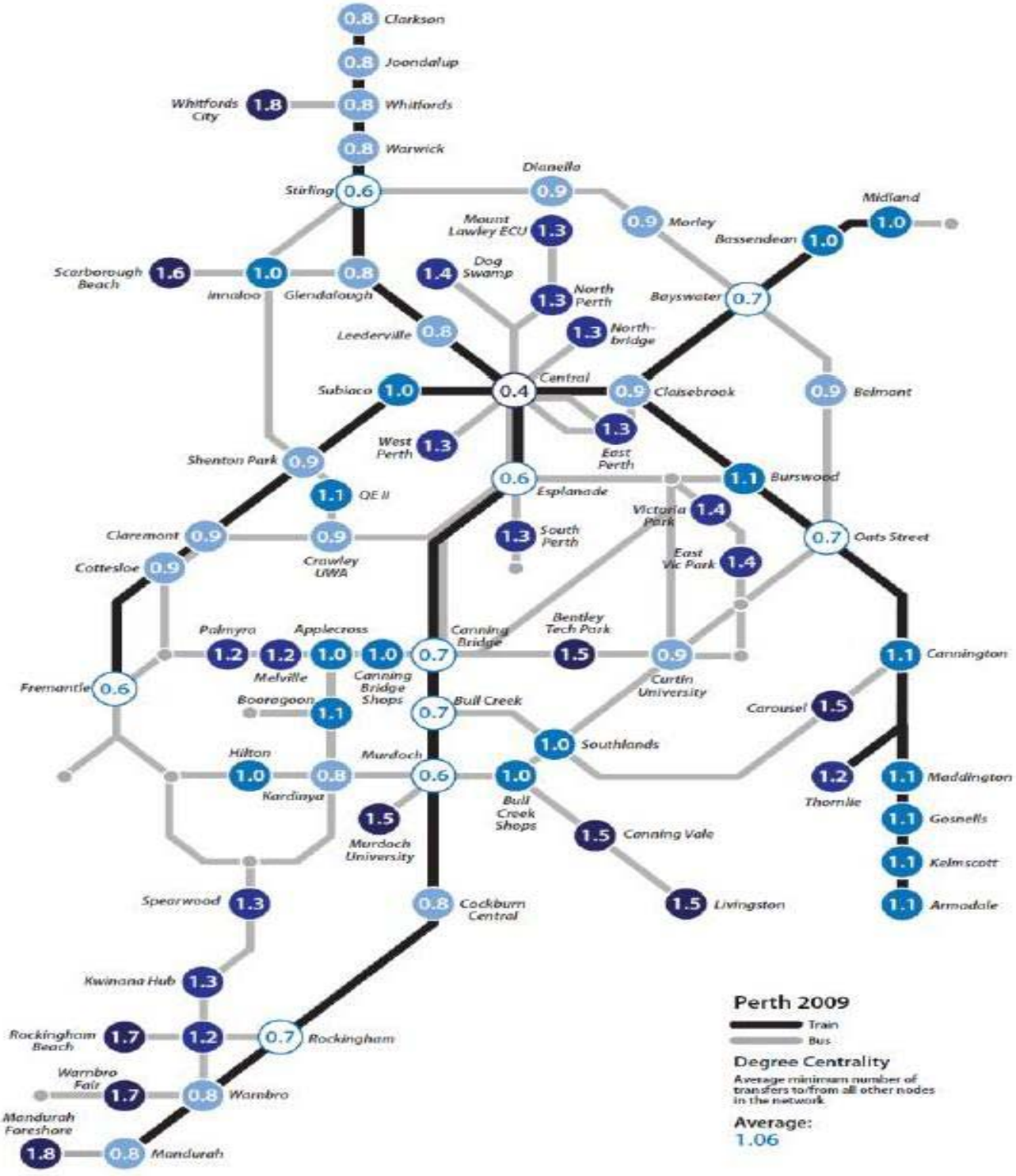
[Courtesy to Monash Institute of Transport Studies for copying this map]

Degree Centrality:

"*This indicator attempts to visualize the need for making transfers between routes or modes while moving across the network*" [Scheurer, 2010; para 4.2].

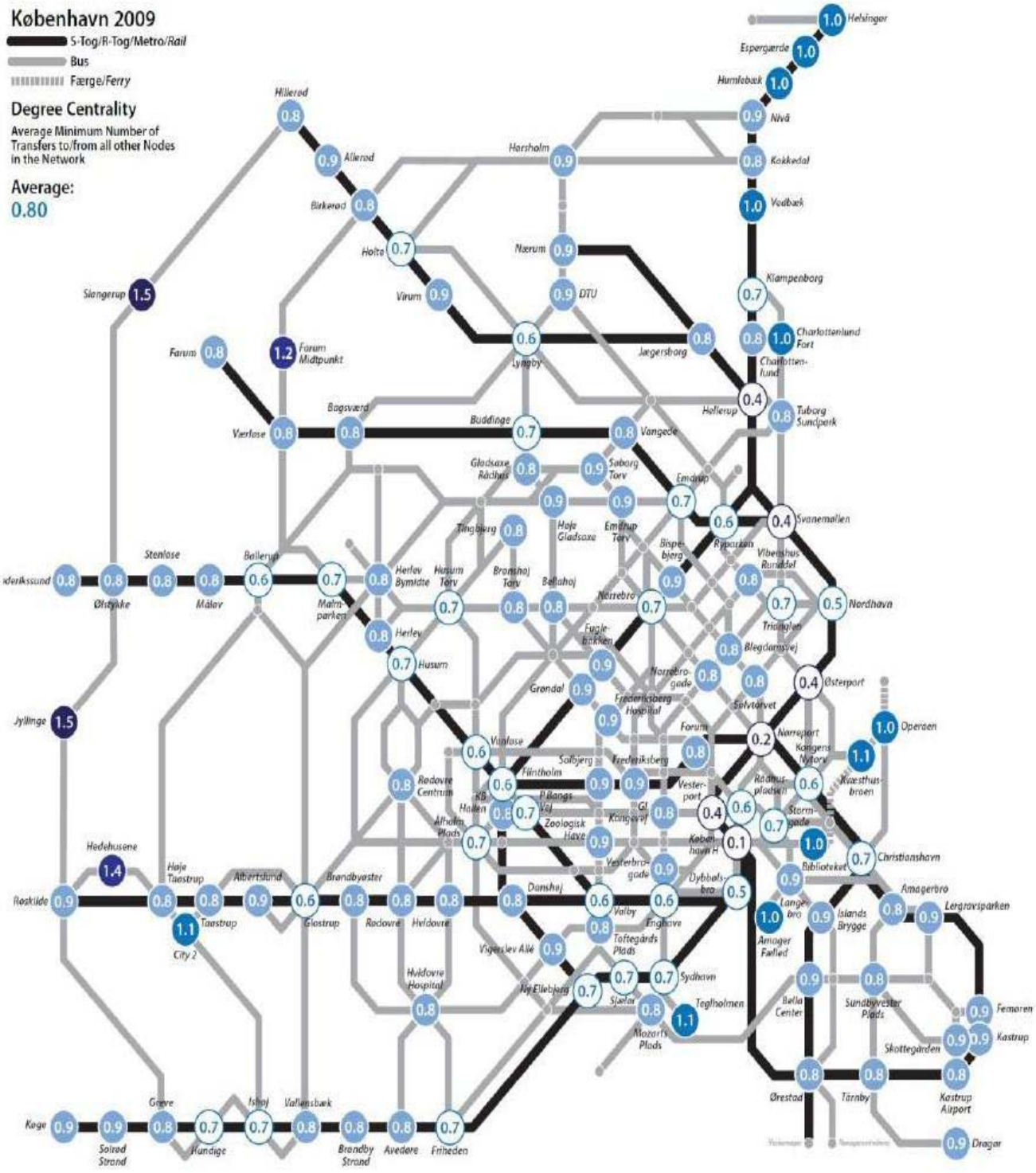
By eliminating all other factors like low-frequency services or longer routes or multimodal, the routes with lowest number of transfers are chosen to compare the performance on both networks. Map-5 and Map-6 on next pages depict average figures per node both for Perth and Copenhagen.

Average degree centrality in Perth is 1.06 transfers per journey, while in Copenhagen it is 0.80. Copenhagen is also leading Perth on this indicator. This difference is because of dense transport network in Copenhagen as can be viewed.



Map-5: Degree Centrality at Perth metropolis transport network

[Courtesy to Monash Institute of Transport Studies for copying this map]



Map-6: Degree Centrality at Copenhagen metropolis transport network

[Courtesy to Monash Institute of Transport Studies for copying this map]

7. Conclusions

For easy comparison of networks of Perth and Copenhagen, results of above parameters are populated in table below:-

Indicator	Perth (2009)	Copenhagen (2009)	Perth (25-years plan)
30-min. contour catchment	11.7%	34.9%	18.1%
Closeness Centrality	56.1	25.9	40.9
Degree Centrality	1.06	0.8	1.0

Table-4: Comparison of SNAMUTS indicator for Perth and Copenhagen

A well-developed urban planning sector of Australia proved its need for economic growth and prosperity in terms of providing and planning for higher quality services to its people. To work effectively, urban planning authorities of a city would require relevant information such as census data, property related information like its value and ownership, demographic maps, transport network maps, information on future trends in public choices, access to emerging technologies and necessary platform for collaborated work. This information when processed using advanced tool like GIS, not only increase transparency but reduce cost in the long run. GIS proves to be an effective and significant tool here, which helps, in planning, coordinating, analyzing and utilizing important database regarding urban features.

"Benefits of using GIS in local government applications include the following: [Pettit, 2003]

- Increase efficiency
- Generate revenue
- Improve accuracy
- Automate tasks
- Increase access to government
- Promote greater collaboration among public agencies
- Save time
- Provide decision support
- Manage resources
- Save money Enhance public participation

8. References

1. Bermhardsen, Tor, 3rd. edition, Geographic Information System --- An Introduction In Chapter-1
2. Scheurer, Dr. Jan, 2010, Benchmarking Accessibility and Public Transport Network Performance in Copenhagen and Perth, In *Australasian Transport Research Forum 2010 Proceedings*
3. Curtis, Professor Carey, 2009, Inquiry into the investment of Commonwealth and State funds in public passenger transport infrastructure and services, In *Australasian Centre for the Governance and Management of Urban Transport, Curtin University*

4. Verma, Ravindra Kumar, and Kumari, Sangeeta, and Tiwary, r. k., not dated, Application of remote sensing and GIS technique for efficient urban planning in India, In *National Institute of Industrial Engineering, Mumbai, India*

5. Clarke, Keith C. and Gaydos, Leonard J., 1998, Loose-coupling a cellular automaton model and GIS: long-term urban growth prediction for San Francisco and Washington/Baltimore, In *Int. J. Geographical information science, 1998, vol. 12, no. 7, 699± 714*

6. TDM Encyclopedia, 2011 In *Victoria Transport Policy Institute*

7. Gioules, Maria, and Hannmann, Lauren, and Smith, Jodi-Lee, 2010, Sustainable Transportation Mapping At The Royal Borough Of Kingston Upon Thames, *Project Report* submitted to the *Faculty of the Worcester Polytechnic Institute downloaded from* http://www.wpi.edu/Pubs/E-project/Available/E-project-062410-173054/unrestricted/RBK_Final_Report-23_June_2010.pdf

8. Pettit, Dr.Christopher, not dated, ESRI solutions: Designing and Mapping the Future of Your Community with GIS In *ESRI webpage bulletin*

9. Bibliography

1. Curtis, Professor Carey, and Scheurer, Dr. Jan, 2010, Network City Activity Centres Developing an analysis, conception and communication tool for integrated land use and transport planning in the Perth metropolitan area, Final Research report submitted to *Australian Housing and Urban Research Institute (AHURI), RMIT University, Melbourne, and Curtin University Sustainability Policy Institute (CUSP), Perth and Australasian Centre for the Governance and Management of Urban Transport Department of Urban and Regional Planning Curtin University of Technology, Perth*

2. Yaakup,Ahris, and Ludin, Ahmad, and others, 2005 “GIS in urban planning and management: Malaysian Experience” In *Journal of Geospatial Solutions for Managing*

the Borderless World 27-29-9-05 retrieved from http://eprints.utm.my/506/2/GIS_IN_URBAN_PLANNIN(2005)Ahris_Yaakup.pdf

3. Newman, Peter and Scheurer, Jan, 2010, the Knowledge Arc Light Rail: A concept for delivering the next phase of public transport in Perth In *Curtin University Sustainability Policy (CUSP) Institute.*

4. Ministry of Municipal Affairs and Housing, Ontario, 2007, A handbook on Municipal Performance Measurement Program.

5. Curtis, Professor Carey, and Scheurer, Dr. Jan, 2008, Spatial Network Analysis of Multimodal Transport Systems: Developing a Strategic Planning Tool to Assess the Congruence of Movement and Urban Structure*, A Case Study of Perth before and after the Perth-to-Mandurah Railway* submitted to *Australian Housing and Urban Research Institute (AHURI), RMIT University, Melbourne, and Curtin University Sustainability Policy Institute (CUSP), Perth and Australasian Centre for the Governance and Management of Urban Transport Department of Urban and Regional Planning Curtin University of Technology, Perth*

6. TUDUR, Robertto Chavez, 2005, GIS: Urban Planning and Management of Cities, A presentation In *ESSD Learning Week of Human Society: Ensuring Sustainable Development*

7. J:\SNAMUTS\perth SNAMUTS report (final) pdf free e-book download from www_abp_unimelb_edu_au.mht

8. J:\SNAMUTS\Urbanet Current projects - SNAMUTS.mht

10. Appendices

All referenced literature used in developing this report is attached as hard copy appendices in serial numbers as in para 8.

(Note: 1-Reference no. 1 is course text book and is not attached herewith),

(Note-2: Bibliography is attached only as soft copy in CD ROM enveloped herewith)

End of Report